



Participation and performance trends in ultracycling

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Abstract: Background: Participation and performance trends have been investigated in ultramarathons and ultratriathlons but not in ultracycling. The aim of the present study was to investigate (1) participation and performance trends in ultraendurance cyclists, (2) changes in cycling speed over the years, and (3) the age of the fastest male and female ultraendurance cyclists. Methods: Participation and performance trends in the 5000 km Race Across America (RAAM) and in two RAAM-qualifier races – the 818 km Furnace Creek 508 in the United States and the 715 km Swiss Cycling Marathon in Europe – were investigated using linear regression analyses and analyses of variance. Results: On average, 41% of participants did not finish either the RAAM or the Furnace Creek 508, whereas 26% did not finish the Swiss Cycling Marathon. Female finishers accounted for 11% in both the RAAM and the Furnace Creek 508 but only 3% in the Swiss Cycling Marathon. The mean cycling speed of all finishers remained unchanged during the studied periods. The winner's average speed was faster for men than for women in the RAAM (22.6 ± 1.1 km · h⁻¹ versus 18.4 ± 1.7 km · h⁻¹, respectively; average speed difference between male and female winners, $25.0\% \pm 11.9\%$), the Swiss Cycling Marathon (30.8 ± 0.8 km · h⁻¹ versus 24.4 ± 1.9 km · h⁻¹, respectively; average speed difference between male and female winners, $27.8\% \pm 9.4\%$), and the Furnace Creek 508 (27.4 ± 1.6 km · h⁻¹ versus 23.4 ± 3.0 km · h⁻¹, respectively; average speed difference between male and female winners, $18.4\% \pm 13.9\%$). In both the Furnace Creek 508 and the Swiss Cycling Marathon, 46% of the finishers were aged between 35 and 49 years. The mean age of winners, both male and female, across the years in the Furnace Creek 508 and in the Swiss Cycling Marathon was 37 ± 10 years. Conclusion: These findings in ultracycling races showed that (1) 26%–40% of starters were unable to finish, (2) the percentage of female finishers was 3%–11%, (3) the gender difference in performance was 18%–28%, and (4) 46% of the successful finishers were master athletes. Future studies need to investigate the reasons for the low female participation and focus on the age-related performance decline in other ultraendurance events in order to confirm that master athletes are predisposed to ultraendurance performances.

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Participation and performance trends in ultracycling

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Background: Participation and performance trends have been investigated in ultramarathons and ultratriathlons but not in ultracycling. The aim of the present study was to investigate (1) participation and performance trends in ultraendurance cyclists, (2) changes in cycling speed over the years, and (3) the age of the fastest male and female ultraendurance cyclists.

Methods: Participation and performance trends in the 5000 km Race Across America (RAAM) and in two RAAM-qualifier races – the 818 km Furnace Creek 508 in the United States and the 715 km Swiss Cycling Marathon in Europe – were investigated using linear regression analyses and analyses of variance.

Results: On average, ~41% of participants did not finish either the RAAM or the Furnace Creek 508, whereas ~26% did not finish the Swiss Cycling Marathon. Female finishers accounted for ~11% in both the RAAM and the Furnace Creek 508 but only ~3% in the Swiss Cycling Marathon. The mean cycling speed of all finishers remained unchanged during the studied periods. The winner's average speed was faster for men than for women in the RAAM ($22.6 \pm 1.1 \text{ km} \cdot \text{h}^{-1}$ versus $18.4 \pm 1.7 \text{ km} \cdot \text{h}^{-1}$, respectively; average speed difference between male and female winners, $25.0\% \pm 11.9\%$), the Swiss Cycling Marathon ($30.8 \pm 0.8 \text{ km} \cdot \text{h}^{-1}$ versus $24.4 \pm 1.9 \text{ km} \cdot \text{h}^{-1}$, respectively; average speed difference between male and female winners, $27.8\% \pm 9.4\%$), and the Furnace Creek 508 ($27.4 \pm 1.6 \text{ km} \cdot \text{h}^{-1}$ versus $23.4 \pm 3.0 \text{ km} \cdot \text{h}^{-1}$, respectively; average speed difference between male and female winners, $18.4\% \pm 13.9\%$). In both the Furnace Creek 508 and the Swiss Cycling Marathon, ~46% of the finishers were aged between 35 and 49 years. The mean age of winners, both male and female, across the years in the Furnace Creek 508 and in the Swiss Cycling Marathon was 37 ± 10 years.

Conclusion: These findings in ultracycling races showed that (1) ~26%–40% of starters were unable to finish, (2) the percentage of female finishers was ~3%–11%, (3) the gender difference in performance was ~18%–28%, and (4) ~46% of the successful finishers were master athletes. Future studies need to investigate the reasons for the low female participation and focus on the age-related performance decline in other ultraendurance events in order to confirm that master athletes are predisposed to ultraendurance performances.

Keywords: ultraendurance, finisher, speed, gender difference, master athlete, cycling

Introduction

In recent years there have been several studies that have investigated participation and performance trends in ultraendurance events,^{1–6} with an ultraendurance event defined as a sport activity lasting more than 6 hours.⁷ These various studies have investigated ultramarathoners in 100 and 161 km ultramarathons,^{1–3,5,8} Ironman triathletes,^{6,9} and ultratriathletes competing in distances longer than an Ironman triathlon.^{4,10–12} Regarding both the participation and the ratio between starters and finishers in

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ultraendurance events, nonfinishers were found to account for ~40% in 161 km ultramarathons.¹ For 161 km ultramarathoners, an exponential increase in the number of finishers was reported.¹ This increase was due to an increase in the participation of athletes over 40 years of age,⁸ an increased percentage of female finishers, and an increased mean number of finishes by single participants, as one athlete participated annually in several ultraendurance races.^{1–3} There seemed to be differences between finishers and nonfinishers regarding race preparation¹⁰ and prerace body composition.^{12–14} Successful finishers in ultraendurance races were found to have invested more time in training^{10,13,14} and to have had a lower percentage of body fat¹³ than nonfinishers.

Regarding the relative participation of each sex, results of the aforementioned studies showed that ~20% of all participants in 161 km ultramarathons were women,^{1–3} while the percentage of women in ultratriathlons was found to be lower, at ~10%.⁴ The age of peak ultraendurance performance has been investigated in ultrarunners¹⁵ and ultratriathletes.^{16,17} Generally, results showed that these ultraendurance athletes were master athletes older than 35 years.¹⁸ In 161 km ultramarathons, ~65%–70% of the finishers were found to be 40 years old and over, and the mean age of the participants was 43–45 years.^{2,3} The fastest race times in 161 km ultramarathons were achieved at the age of 40–49 years for women and 30–39 years for men.^{1–3} In 100 km ultramarathoners, women could achieve a high level of performance up to the age of 54 years.⁵ In both Ironman triathletes¹⁶ and triathletes competing in a Triple Iron ultratriathlon and a Deca Iron ultratriathlon,¹⁷ the age of peak performance was at ~35 years.

Not only participation increased in master athletes, but also the best performances have been achieved by master athletes in ultraendurance races where master athletes are defined as athletes aged > 35 years.^{9,15,17,18} It appears that the age of peak performance is higher for ultraendurance events^{15–17} than for shorter events such as 42 km marathons, where peak performance was still achieved at ~25–35 years^{19–21} – this is still older than the age of peak performance found in other sports disciplines such as baseball (28 years), tennis (24 years), and golf (31 years).²⁰ However, master marathoners have been found to improve their running times at a faster rate than younger athletes,²² and it is hypothesized that both male and female master marathoners have probably not yet reached their performance limits.²³

There have been several studies that have investigated the performance trends in ultraendurance races.^{1,4,6} Knechtle et al⁴ compared female and male performances in a Deca Iron ultratriathlon, where athletes performed a 3.8 km

swim, 180 km cycle, and a 42.2 km run ten times. Men were ~19% faster than women in the cycle split, and ~30% faster for the total Deca Iron ultratriathlon. Lepers⁶ reported no significant improvements in performance in the Ironman Hawaii, apart from an initial increase in speed in the early 1980s. This enhancement of performance was probably due to important technological improvements in bicycles that occurred at that time.²⁴

While participation and performance trends were investigated in ultramarathoners and ultratriathletes, participation and performance trends in ultraendurance cycling remain unclear, although this discipline is well identified.²⁵ Until now, no study has investigated participation and performance trends in ultraendurance cycle races. It has been reported that between 2008 and 2010, ~49% of the participants in the 715 km Swiss Cycling Marathon did not finish the race.¹³ However, the premier ultraendurance cycle race is the 5000 km Race Across America (RAAM).²⁶

The aim of the present study was to investigate (1) participation and performance trends in ultraendurance cyclists, (2) changes in cycling speed over the years, and (3) the age of the fastest male and female ultraendurance cyclists. Based upon existing literature on ultrarunning and ultratriathlon, the authors hypothesized (1) an increase in female participation, (2) a gender difference in performance of ~20%–30%, and (3) an age of peak ultracycling performance of ~35 years. To test these hypotheses, the authors investigated participation and performance trends in two RAAM-qualifier races and in the RAAM itself. Because the age of the participants was not available in the results of the RAAM, the authors considered the two ultracycling qualifying races, the Furnace Creek 508 and the Swiss Cycling Marathon, in order to investigate the age-related decline in performance.

Materials and methods

The Institutional Review Board of St Gallen, Switzerland, approved this study with a waiver for the requirement of an informed consent, given that the study involved the analysis of publicly available data. The cycling performances and the ages of both male and female finishers in three different ultraendurance cycle races were chosen and analyzed.

Races and data sampling

The data sets for this study were obtained from the individual race websites and from the race directors. The authors investigated the RAAM data available from 1982 to 2011.²⁶ The RAAM spans a distance of ~5000 km and has a total elevation of ~30,500 m. It is the longest, and considered

the hardest, cycling endurance event in the world, starting at the Pacific coast and ending at the Atlantic coast in the United States. Solo riders have to complete the race within 12 days, so a mean speed of $17 \text{ km} \cdot \text{h}^{-1}$ is demanded, including noncycling times. Winning solo riders have completed the race in 8 days and a few hours, corresponding to a mean speed of $\sim 25 \text{ km} \cdot \text{h}^{-1}$. To participate in the RAAM as a solo rider, ultraendurance athletes have to pass the requirements of qualifying races. The authors considered two of these qualifying races in order to obtain data about ages that were not available for the RAAM. The authors investigated the Furnace Creek 508 data available from 1989 to 2011 – the Furnace Creek 508 is a US RAAM-qualifier race that is 818 km long, with an elevation gain of over $\sim 11,000 \text{ m}$.²⁷ The authors also analyzed the Swiss Cycling Marathon data available from 2001 to 2011 – the Swiss Cycling Marathon is the oldest and largest RAAM-qualifier race in Europe, where the participants have to cover a distance of 715 km with an overall elevation gain of $\sim 5580 \text{ m}$.²⁸

Age of the participants and their cycling performances

The changes over time in the ages of all participants, together with the average cycling speed in kilometers per hour for the male and female winners and all male finishers, were analyzed for both the Furnace Creek 508 (data from 1989 to 2011) and the Swiss Cycling Marathon (data from 2001 to 2011). Because the age of the participants was not available for the RAAM, the authors only considered the average cycling speed of the male and female winners and all male finishers of the RAAM (data from 1982 to 2011). Because of the small percentage of female finishers in the three races, less than 11% of the total finishers over the studied periods (Figure 1), the authors focused on male finishers only. The magnitudes of the gender difference were examined by calculating, as a percentage, the difference in cycling speed between male and female winners.

Age-related changes in performance

In order to analyze the age-related change in ultracycling performances, the authors pooled the data of the male finishers of the Furnace Creek 508 from 1989 to 2011 and the male finishers of the Swiss Cycling Marathon from 2001 to 2011. The authors identified the following age groups: 18–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, and ≥ 60 years. In order to limit the influence of environmental conditions over the years, the cycling performances were expressed as a percentage of the winner's speed in each year.

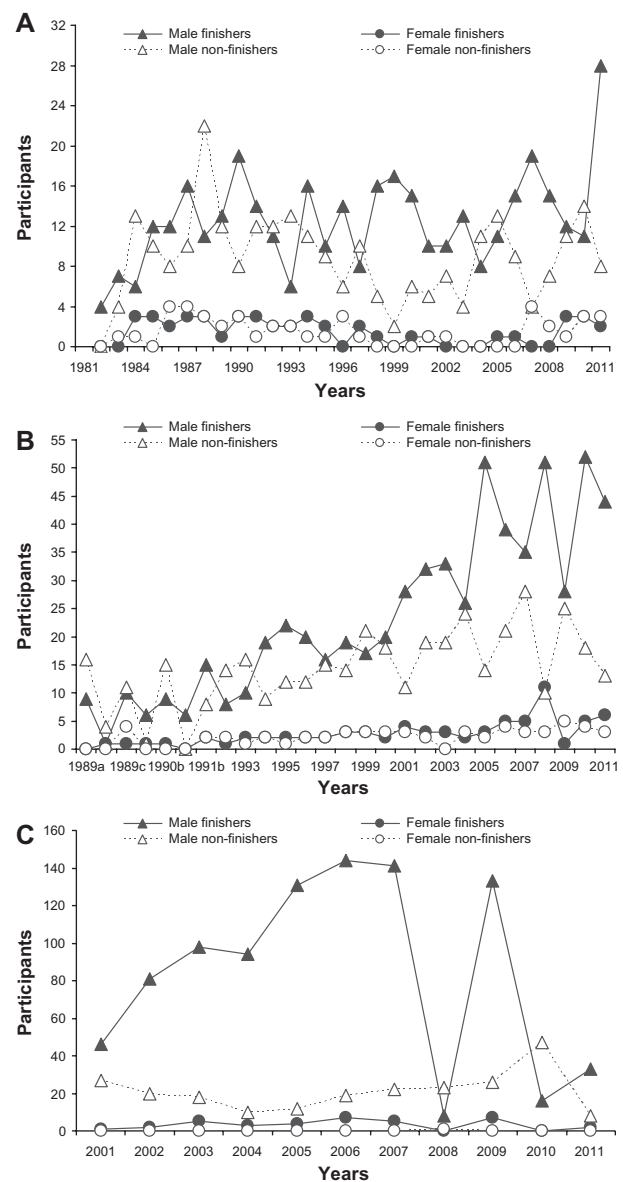


Figure 1 Number of male and female finishers and nonfinishers in three different ultraendurance cycle races, from the first year of the event through to 2011: (A) the Race Across America (United States), (B) the Furnace Creek 508 (United States), and (C) the Swiss Cycling Marathon (Switzerland).

Note: (B) From 1989 to 1991 there was more than one race per year.

Finally, the authors considered the performances of the best ten male cyclists per age group over time.

Statistical analysis

Data are reported as the mean plus or minus the standard deviation. Linear regressions were used for estimating the changes in the selected variables for each year of the races. Pearson's correlation coefficients were used to assess the association between various variables (Statistica, v 6.1; StatSoft, Inc, Tulsa, OK, USA). An unpaired Student's *t*-test was used to compare the ages of the female and the male winners.

One-way analysis of variance was used to compare the cycling performances of the different age groups for male cyclists. Tukey's post hoc analyses were used to test differences within the one-way analysis of variance when appropriate. Statistical significance was accepted at $P < 0.05$.

Results

Participation trends

The annual number of male and female finishers and non-finishers over time are shown in Figure 1. From 1982 to 2011 there were 424 finishers (45 women and 379 men) and 310 nonfinishers (44 women and 266 men) in the RAAM (Figure 1A). Nonfinishers represented, on average, $41\% \pm 15\%$ of the total starters, and women accounted, on average, for $11\% \pm 9\%$ of the total finishers over the 29-year period. From 1989 to 2011 there were 703 finishers (77 women and 626 men) and 445 nonfinishers (57 women and 388 men) in the Furnace Creek 508 (Figure 1B). Nonfinishers represented, on average, $41\% \pm 15\%$ of the total starters, and women accounted, on average, for $11\% \pm 9\%$ of the total finishers over the 22-year period. The percentage of male finishers in each age group over the studied period was 1.6%, 4.5%, 8.9%, 17.4%, 24.6%, 20.9%, 13.3%, 5.7%, and 3.0% for the age groups 18–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, and ≥ 60 years, respectively. From 2001 to 2011 there were 961 finishers (36 women and 925 men) and 233 nonfinishers (one woman and 232 men) in the Swiss Cycling Marathon (Figure 1C). Nonfinishers represented, on average, $26\% \pm 20\%$ of the total starters, and women accounted, on average, for $3\% \pm 2\%$ of the total finishers over the 10-year period. The percentage of male finishers in each age group was 1.9%, 6.6%, 13.1%, 18.2%, 19.0%, 18.8%, 12.7%, 4.8%, and 4.9% for the age groups 18–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, and ≥ 60 years, respectively.

Performance trends for winners

Figure 2 shows the historical performance trends of the male and female winners for the three ultraendurance cycling races. In the RAAM, the mean winner's cycling speed was $22.6 \pm 1.1 \text{ km} \cdot \text{h}^{-1}$ for men and $18.4 \pm 1.7 \text{ km} \cdot \text{h}^{-1}$ for women (Figure 2A), and this did not change over time for either sex. The average speed difference between the male and female winners was equal to $25.0\% \pm 11.9\%$. In the Furnace Creek 508, the mean winner's cycling speed was $27.4 \pm 1.6 \text{ km} \cdot \text{h}^{-1}$ for men and $23.4 \pm 3.0 \text{ km} \cdot \text{h}^{-1}$ for women (Figure 2B). The gradient of the regression line demonstrates that male cycling speed increased significantly by $0.14 \text{ km} \cdot \text{h}^{-1}$ per year from

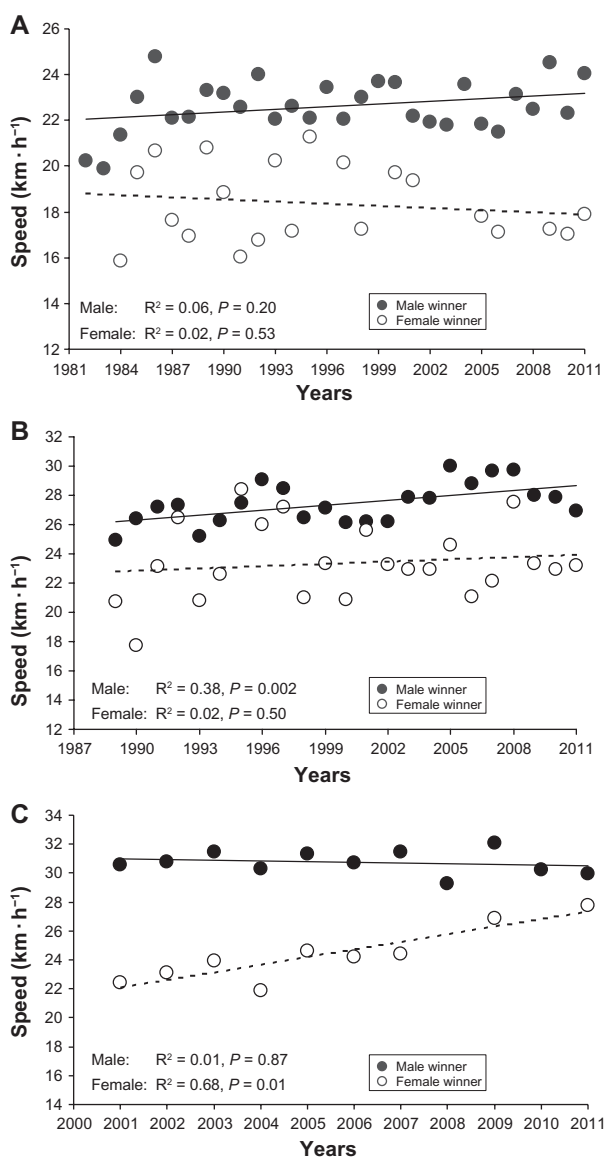


Figure 2 Mean speed of male and female winners in three different ultraendurance cycle races, from the first year of the event through to 2011: (A) the Race Across America (United States), (B) the Furnace Creek 508 (United States), and (C) the Swiss Cycling Marathon (Switzerland).

Note: The solid line represents the linear regressions for men and the dotted line represents the linear regressions for women.

1989 to 2011. In contrast, the female winner's speed did not significantly change over the years. The average speed difference between the male and female winners was equal to $18.4\% \pm 13.9\%$. In the Swiss Cycling Marathon, the mean winner's cycling speed was $30.8 \pm 0.8 \text{ km} \cdot \text{h}^{-1}$ for men and $24.4 \pm 1.9 \text{ km} \cdot \text{h}^{-1}$ for women (Figure 2C). The gradient of the regression line demonstrates that female cycling speed increased significantly by $0.48 \text{ km} \cdot \text{h}^{-1}$ per year from 2001 to 2011. In contrast, the male winner's speed did not significantly change over the years. The average speed difference between the male and female winners was equal to $27.8\% \pm 9.4\%$.

Performance trends for finishers

Figure 3 shows the historical performance trends of the male finishers in the three ultra-endurance cycle races. In the RAAM, the mean finishers' cycling speed was $19.4 \pm 0.7 \text{ km} \cdot \text{h}^{-1}$ (Figure 3A), and the speed did not significantly change over the years. In the Furnace Creek 508, the mean finishers' cycling speed was $21.8 \pm 0.9 \text{ km} \cdot \text{h}^{-1}$ (Figure 3B) and did not significantly change over the years. In the Swiss Cycling Marathon, the mean finishers' cycling speed was $22.2 \pm 1.6 \text{ km} \cdot \text{h}^{-1}$ (Figure 3C); the gradient of the regression line demonstrates that the finishers' cycling speed increased significantly, by $0.32 \text{ km} \cdot \text{h}^{-1}$ per year, from 2001 to 2011.

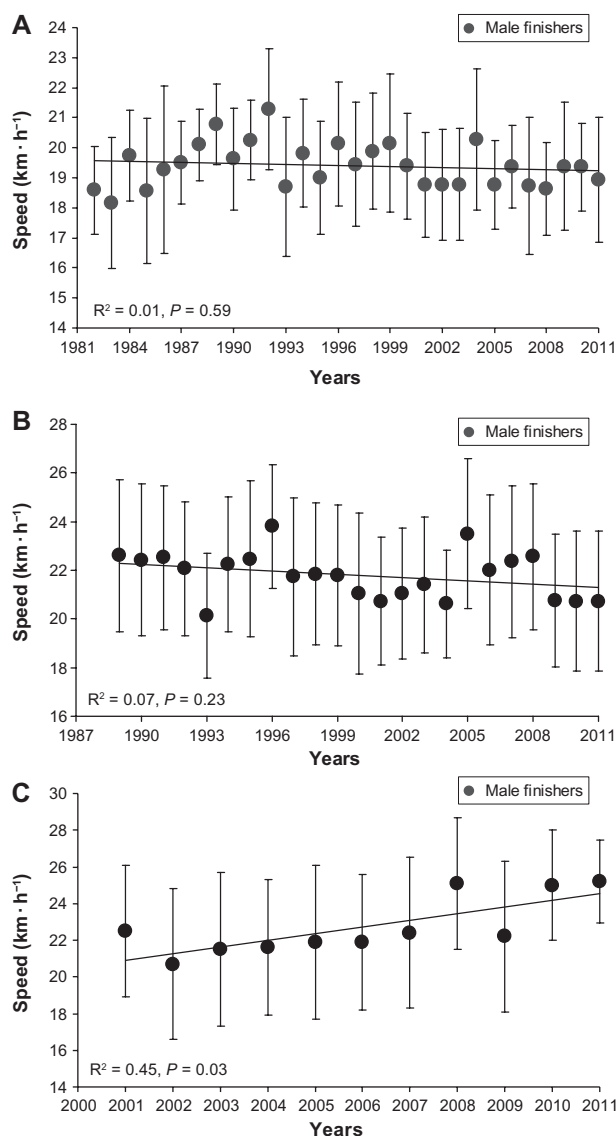


Figure 3 Mean speed of all male finishers in three different ultraendurance cycle races, from the first year of the event through to 2011: (A) the Race Across America (United States), (B) the Furnace Creek 508 (United States), and (C) the Swiss Cycling Marathon (Switzerland).

Age of winners

Figure 4 shows the historical age trends of the male and female winners in the Furnace Creek 508 and the Swiss Cycling Marathon. In the Furnace Creek 508, the mean age of winners was the same for men (36 ± 7 years) and women (37 ± 7 years) over time (Figure 4A). The winner's age did not significantly change over the years for men, but the gradient of the regression line demonstrates that the female winner's age increased significantly, by 0.6 years per year, from 1989 to 2011. In the Swiss Cycling Marathon there was no difference in the mean age of winners between men (38 ± 4 years) and women (36 ± 9 years) during the studied period (Figure 4B), and this did not change significantly over the years for either sex.

Age of finishers

Figure 5 shows the historical age trends of the male finishers in the Furnace Creek 508 and the Swiss Cycling Marathon. In the Furnace Creek 508, the mean age of finishers was 41 ± 4 years during the studied period (Figure 5A). The gradient of the regression line demonstrates that the age of male finishers increased significantly, by 0.47 years per year, from 1989 to 2011. In the Swiss Cycling Marathon,

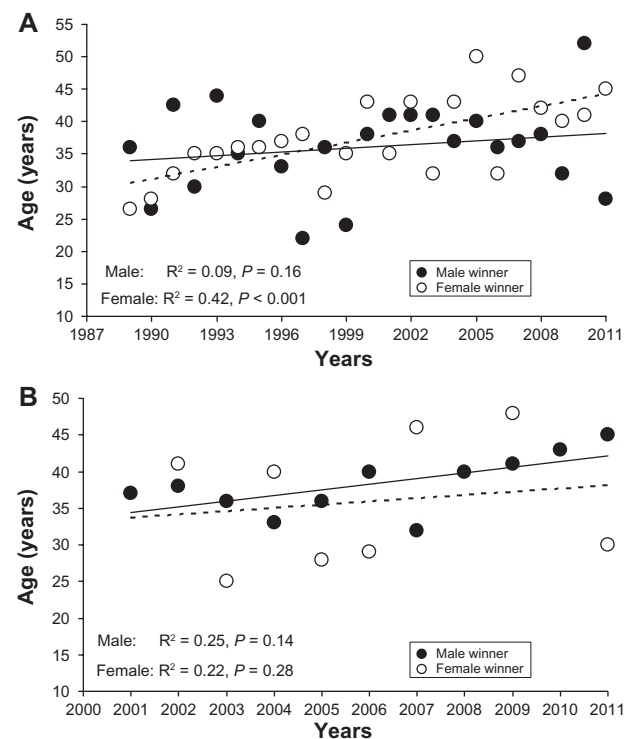


Figure 4 Ages of male and female winners in two different ultraendurance cycle races, from the first year of the event through to 2011: (A) the Furnace Creek 508 (United States) and (B) the Swiss Cycling Marathon (Switzerland).

Note: The solid line represents the linear regressions for men and the dotted line represents the linear regressions for women.

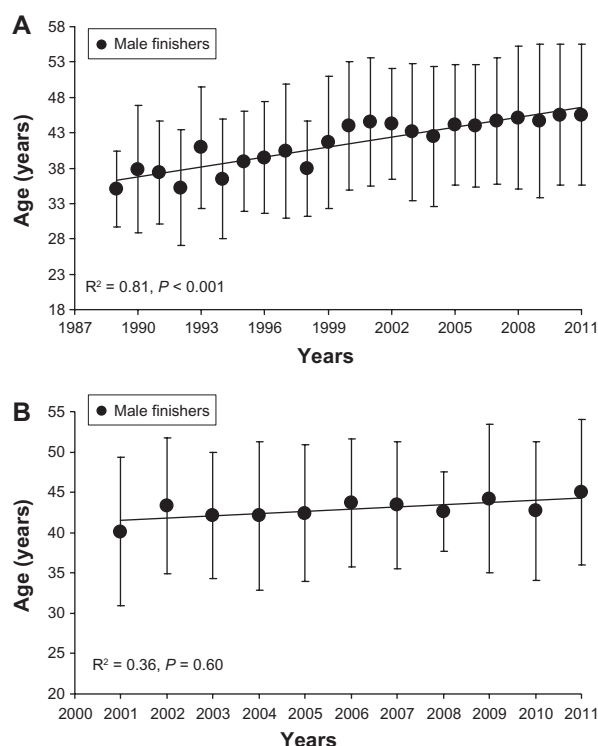


Figure 5 Ages of all male finishers in two different ultraendurance cycle races, from the first year of the event through to 2011: (A) the Furnace Creek 508 (United States) and (B) the Swiss Cycling Marathon (Switzerland).

the mean age of finishers was 43 ± 1 year during the studied period (Figure 5B), and this did not change significantly over the years.

Age-related changes in performances

The mean age-related changes in male cycling speed in the Furnace Creek 508 and the Swiss Cycling Marathon are shown in Figure 6. The cycling speed increased in a curvilinear manner with advancing age. There was a significant age effect in cycling performance (Furnace Creek 508, $F = 24.6$, $P < 0.001$; Swiss Cycling Marathon, $F = 31.2$, $P < 0.001$). For both races, no significant difference in cycling performance was observed in the five age groups between the 25- and 49-year marks, but cycling speed was significantly ($P < 0.01$) slower in the 18- to 24-year age group and the age groups over the 50-year mark than in the age groups between the 25- and 49-year marks.

Discussion

The present study investigated participation and performance trends in ultraendurance cycling races, the changes in cycling speed over time, and the age of the fastest male and female ultraendurance cyclists. The authors hypothesized that female participation would increase, the gender difference

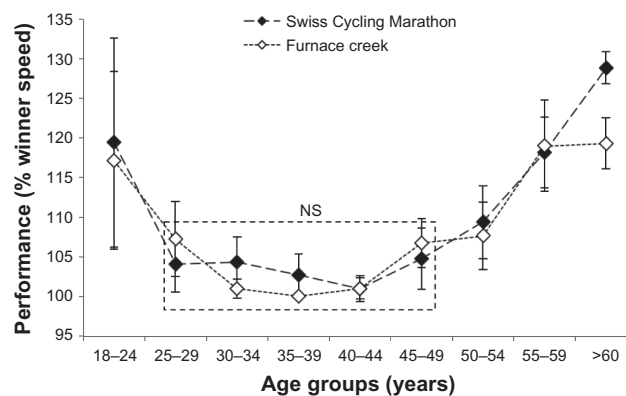


Figure 6 Age-related changes in male cycling performance expressed as a percentage of the winner's speed (% winner speed) in two ultraendurance cycle races: the Swiss Cycling Marathon (Switzerland) and the Furnace Creek 508 (United States).

Notes: Data were pooled from the first year of each event through to 2011. In both races the cycling speed was significantly ($P < 0.01$) slower for athletes in the 18- to 24-year age group and those over 50 years of age than for those athletes between 25 and 49 years of age.

Abbreviation: NS, nonsignificant.

in ultracycling performance would be at ~20%–30%, and the age of peak ultracycling performance would be at ~35 years.

Participation trends

An interesting finding was that ~41% of the starters did not finish the RAAM. The same percentage did not finish the Furnace Creek 508, while ~26% did not finish the Swiss Cycling Marathon. In the RAAM, covering a distance of ~5000 km, the percentage of nonfinishers remained the same as in the Furnace Creek 508, which is 818 km long. The percentage of nonfinishers in the RAAM might be relatively low when looking at its distance, because the athletes have to qualify for the RAAM, as opposed to the Furnace Creek 508 or the Swiss Cycling Marathon, and so athletes participating in the RAAM might be better prepared because of successful completion of previous races.^{10–14,29} Further explanations in favor of the relatively low percentage of nonfinishers in the RAAM could be more cycling training hours,^{10–13,30} a higher cycling speed in training,^{13,30} or a more adequate nutrition¹³ than those racing in the Furnace Creek 508, so, consequently, the percentage of nonfinishers did not increase with the longer distance in the RAAM as the authors hypothesized.

A further important finding was the low overall number of women in all the investigated ultracycling races. In the RAAM, women accounted, on average, for ~11% of participants, the same as in the Furnace Creek 508. In the Swiss Cycling Marathon, the percentage of women was very low, at ~3%. The percentage of female participants was higher,

at ~27%, than for other ultraendurance races such as the Ironman Hawaii.^{6,9} In races longer than the marathon distance, the percentage of female participation decreased as the race distance increased. In 161 km ultramarathons ~20% of participants were women,¹⁻³ and in ultratriathlons no more than 10% of women participated.⁴ The low number of female finishers might be explained by differences in motivation between female and male ultraendurance athletes. Physically active men seemed to have a different motivation to compete in races than women. Krouse et al³¹ described female ultrarunners as task-oriented, internally motivated, health conscious, and financially conscious individuals. Male endurance athletes seem to rather prefer sports requiring skills needed for success in male-to-male physical competition,³² and men seem to have a greater training motivation than women.^{33,34}

Performance trends

An important finding in the present study was that the difference in the mean cycling speed of the male and female winners was ~24%. It has been speculated that the difference between female and male performances could disappear over longer distances.³⁵ A potential reason why men were faster than women might be their greater muscle mass and their greater aerobic capacity.^{36,37} Hoffman¹ observed, in 161 km ultramarathons, that the relative improvement in performance was greater in women than in men in the early 1980s. Hoffman⁸ also showed that by matching women and men in performances at 42.2 or 56 km and comparing them later at 80 and 161 km distances, the female performance was not relatively better. Coast et al³⁸ noticed that the mean male performance in a 200 km ultrarun was better than the mean female performance, and Hoffman¹ confirmed the same result in 161 km ultramarathons. Knechtle et al⁴ demonstrated – in

a Double Iron ultratriathlon, a Triple Iron ultratriathlon, and a Deca Iron ultratriathlon, where athletes have to compete twice, three times, or ten times the Ironman distance (a 3.8 km swim, a 180 km cycle, and a 42.2 km run) – that the gender difference increased with increasing race distance. In the cycling split in a Double Iron ultratriathlon, a Triple Iron ultratriathlon, and a Deca Iron ultratriathlon, the gender difference was ~21%, which was closer to the present findings.⁴ However, these studies could not confirm the assumption that the gender difference in performance would disappear with longer distances.³⁵

The average speed in ultraendurance cycling showed no change over the years for either winners or finishers. The winner's speed increased in the Furnace Creek 508 for men by 0.14 km · h⁻¹ per year and in the Swiss Cycling Marathon for women by 0.48 km · h⁻¹ per year. The speeds of male finishers in the Swiss Cycling Marathon changed by 0.32 km · h⁻¹ per year. In the RAAM, only an initial increase in performance in the early 1980s was obvious. A previous study showed that even an increase in participation in 161 km ultramarathons was not associated with a growth in competition and performance – the limited financial incentive was assumed to be the reason.¹ An initial increase in speed was also reported in Ironman Hawaii in the early 1980s,⁶ at the same time as important technological improvements in bicycles were made.²⁴ These technological improvements concerned the factor of aerodynamics, so the mean velocity increased because the primary force inhibiting forward motion is air resistance.²⁴

Age trends

Interestingly, 72.9% of the male finishers in the Furnace Creek 508 and 56% in the Swiss Cycling Marathon were master athletes in the age groups between 35 and 49 years.

Table 1 Age group in which, and age at which, fastest swim performance achieved for male athletes

Swim type	Mean age group in which fastest performance achieved (years)	Mean age when peak performance achieved (years)	References
50 m	20–30	–	Tanaka and Seals ⁴³
50 m	–	23.1	Berthelot et al ⁴⁴
50 m	–	26–27	Rüst et al ⁴⁵
100 m	–	21.4 ± 3.1 ^a	Schulz and Curnow ²⁰
400 m	–	19.9 ± 2.2 ^a	Schulz and Curnow ²⁰
1500 m	20–45	–	Tanaka and Seals ⁴³
1500 m	–	18.4	Berthelot et al ⁴⁴
1500 m	–	20.3 ± 3.5 ^a	Schulz and Curnow ²⁰
1500 m	–	26–27	Rüst et al ⁴⁵
26.4 km, open water	–	26.8 ± 0.5 ^a	Eichenberger et al ⁴⁶
12-hour swim	30–49	–	Eichenberger et al ⁴⁷

Note: ^aData presented as mean plus or minus standard deviation.

In the Furnace Creek 508, the mean age of male finishers increased significantly, by 10 years since 1989, or 0.47 years per year. The reason why master athletes up to the age of 49 years participate and successfully finish in such numbers in ultracycling events could be optimal conditions in physiology, biomechanics, psychology, tactics and health/lifestyle,⁷ more training hours than other participants,^{10,12} and an increased prerace experience.^{10–13,29} The aforementioned studies have already highlighted that participants may successfully finish ultraendurance events when they fulfill these aspects. In 161 km ultramarathons a large increase in the number of finishers was due to an increased participation of master athletes over 40 years of age.^{1–3} Half of the runners were aged between 37 and 49 years, corresponding to an increase of 10 years in mean age since the late 1970s. Actually, the mean age in peak running speed is at around 43–45 years.^{1–3} Master athletes might be predisposed to successfully finish an ultraendurance event.

Based upon previous studies describing the age of peak performance in both 161 and 100 km ultramarathoners, the authors hypothesized an age of peak ultracycling performance of ~35 years.¹⁸ In both the Furnace Creek 508 and the Swiss Cycling Marathon, the athletes achieved their peak ultracycling performance at the age of ~37 years. The cycling speed was fastest in the age groups between the 25- and 49-year marks. No significant difference was observed within these age groups, although most finishers were in the age groups between the 35- and 49-year marks. The decrease in performance after the age of 49 years could be because of declining capacities – mainly a loss in lung capacity,³⁹ a loss

of cardiac output,⁴⁰ a loss in skeletal muscle mass,⁴¹ and an increase in frailty.⁴² The decrease in endurance performance seemed to be primarily due to the cardiopulmonary system and its age-related decrease in peak oxygen uptake.¹⁸

In other sports, the age of peak performance was reached at a younger age than in ultracycling events: 25–35 years in marathons, 28 years in baseball, 24 years in tennis, and 31 years in golf.²⁰ In 161 km ultramarathons, the maximal performance was achieved at 30–39 years in men and at 40–49 years in women.^{1–3} In a 100 km ultramarathon, the best times for women were observed at 30–54 years,⁵ so, consequently, even older athletes were able to achieve outstanding performances in ultraendurance events. In marathons, master athletes improved their running times at a greater rate than younger athletes²² and have probably not yet reached their limits.²³ Table 1 presents the age groups of the fastest swim performances and the age of peak swim performance for distances from 50 m to ~38 km. The age of the athlete with the fastest swim performance increased as the swim distance increased. The same findings were made for running (Table 2) and triathlon (Table 3), where the age of peak endurance performance increased as the race distance increased.

The advantages of master athletes leading to a successful participation in ultraendurance races, such as increased prerace experience^{10–13,29} and more training hours than other participants,^{10,12–14} seemed to compensate for the age-related changes in performance. The performance of those over 50 years of age had much less to do with this biological deterioration. Huonker et al⁴¹ showed that the aerobic

Table 2 Age group in which, and age at which, fastest run performance achieved for male athletes

Distance	Mean age group in which fastest performance achieved (years)	Mean age when peak performance achieved (years)	References
100 m	–	22.8 ± 2.3 ^a	Schulz and Curnow ²⁰
200 m	–	23.5 ± 2.1 ^a	Schulz and Curnow ²⁰
800 m	–	23.7 ± 2.7 ^a	Schulz and Curnow ²⁰
1500 m	–	24.8 ± 2.9 ^a	Schulz and Curnow ²⁰
5000 m	–	27.2 ± 3.9 ^a	Schulz and Curnow ²⁰
10,000 m	–	23.3	Berthelot et al ⁴⁴
10,000 m	–	27.5 ± 4.1 ^a	Schulz and Curnow ²⁰
Marathon	–	27.8 ± 4.5 ^a	Schulz and Curnow ²⁰
Marathon	–	28.9 ± 3.8 ^a	Hunter et al ²¹
Marathon	–	31.6	Berthelot et al ⁴⁴
78 km ultramarathon	–	33.9 ± 4.2 ^a	Eichenberger et al ¹⁵
100 km ultramarathon	30–49	–	Knechtle et al ¹⁷
161 km ultramarathon	30–39	–	Hoffman ¹
161 km ultramarathon	30–49	–	Hoffman and Wegelin ³
250 km ultramarathon	–	37 ± 8 ^a	Knoth et al ⁴⁸

Note: ^aData presented as mean plus or minus standard deviation.

Table 3 Age group in which, and age at which, fastest triathlon performance achieved for male athletes

Distance	Mean age group in which fastest performance achieved (years)	Mean age when peak performance achieved (years) ^a	References
1.5, 40, 10 km	18–34		Etter et al ⁴⁹
1.9, 90, 21.1 km	18–39		Knechtle et al ⁵⁰
3.8, 180, 42.2 km	30–39		Lepers and Maffiuletti ⁹
3.8, 180, 42.2 km		33 ± 3	Rüst et al ¹⁶
3.8, 180, 42.2 km		34 ± 3	Rüst et al ⁵¹
11.4, 540, 126.6 km	25–44		Knechtle et al ¹⁷
11.4, 540, 126.6 km		38.5 ± 3.3	Knechtle et al ¹⁷
38, 1800, 422 km	25–44		Knechtle et al ¹⁷
38, 1800, 422 km		41.3 ± 3.1	Knechtle et al ¹⁷

Notes: ^aData presented as mean plus or minus standard deviation. The distance column shows the split distances for swimming, cycling and running.

muscular energy metabolism begins to decrease in the fourth or fifth decade of life. These energy reserves are needed for an extremely exhausting and challenging ultracycle, particularly the RAAM. A previous case report showed the energy expenditure of a solo rider in the RAAM where he burned off 17,965 kcal a day,⁵² and Hulton et al⁵³ showed that this was three times the energy intake.

Limitations and implications for future studies

Several variables with an influence on performance in an ultraendurance sport are known, such as weather influences^{54–56} and adequate nutrition.^{13,52,53,57,58} Unfortunately, these aspects were not considered in the present study. The most important limitation was that the age of athletes was not recorded in the RAAM data, so the authors had to consider two RAAM-qualifier races in order to investigate the age of peak performance. Other limitations were missing data regarding training^{10–14} and prerace experience.^{10,12,14,29} Consequently, the authors could not investigate whether increased prerace experience also leads to a better performance in ultracycling races as it has been shown to do, for instance, in a Triple Iron ultratriathlon,¹⁰ and whether this is an important reason why the mean age of winners in ultraendurance sports is older than the mean age of winners in non-ultraendurance sports.

Conclusion

The results of this study show that (1) 30%–40% of starters in ultracycling races were unable to finish, (2) the percentage of female finishers was 3%–11%, (3) the gender difference in performance was 18%–28%, and (4) ~50% of the successful finishers were master athletes. Future studies should investigate the reason for the low percentage of female participation and should focus on the age-related decline in

other ultraendurance events in order to confirm that master athletes are predisposed to ultraendurance performances.

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Disclosure

The authors report no conflicts of interest in this work.

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